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Design, Modelling and Simulation of an Improved Manual Tyre- Changer Machine

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Abstract- The conceptual designs for the manual tyre-changer machine (MTCM) was generated, detail design of the MTCM as well as proper material selection for the MTCM was carried out, and ultimately, the performance of the designed and fabricated MTCM was modeled and simulated. The results from the analysis showed that the design of improved manual tyre changer machine has mechanical advantage of bead breaker arm of 8.67, wall thickness of bead breaker arm of 4.8738mm, allowable bending stress of 80 N/mm2, allowable shear stress 40 N/mm2, shank diameter of bolt at A 10.84949mm, shank diameter of bolt at B 11.3743mm, height/thickness of nut at A and B 9.6mm, length of a side of the outer square section of insertion/extraction arm based on bending stress is 46.296mm, length of a side of the inner square section of mount/demount arm based on bending stress 38.58mm, angle of twist of a 60mm × 60mm × 5mm insertion/extraction arm while inserting/extracting a tyre on 16" × 7" rim was selected due to its lower angle of twist of 3.6848×10-9 rad. The circular pitch for the pinion gear was determined as 9.426mm.The circular pitch for the driven gear is determined as 6.284mm.The module for the pinion gear was determined as 3mm.The module for the driven gear was determined as 2.4mm.The number of teeth for pinion gear is determined as 20.The number of teeth for driven gear was determined as 30. The torque on driven gear is 4340.02N-mm and the force acting on gear teeth was determined as 144. 67N. The contact stress for the pinion gear was determined as 4.00N/m2. The ANSYS simulation results also showed that the maximum value of equivalent stress for the MTCM roller bearing was 3.2406Pa, the maximum value of equivalent elastic strain for the MTCM roller bearing was 7.8388 x 10-10m/m and the maximum value of total deformation for the MTCM roller bearing was 5.7215 x 10-8m. Conclusion and recommendations were made that ANSYS simulation tool applied in this study have shown that it is possible to predict how the machine components will behave in a real case and allows the engineer to see where the stresses, strains and total deformations will be the greatest and how the machine will behave with such occurrence to provide better reference for redesign of the machine.

Keywords- Design, Lever, Tyre Changer.

I. INTRODUCTION

1. Background to the Study

A tyre is one of the components of a wheel that takes the form of a ring and is wrapped around the circumference of the rim. Its function is to transfer the weight of a vehicle from the axle to the wheel and then to the ground below, as well as to generate traction for the surface that the vehicle is driven over (Boardman, 2007). Pneumatic inflation is utilized for the great majority of tyres, which includes those that are used on vehicles and bicycles. These tyres provide a solid support system for cars in addition to providing a flexible cushion that absorbs shocks as the tyre rolls over rough parts on the road surface.

In addition to carbon black and other chemical compounds, the production of contemporary pneumatic tyres necessitates the use of a number of materials, including natural rubber, synthetic rubber, fabric, and wire. The body and the tread are two terms used to describe the parts of a pneumatic tyre. The tyre's internal wheel-mounted casing determines its ability to hold a specific volume of compressed air. The part of the tyre that touches the ground is known as the tread, and it is this portion of the tyre that is in charge of generating traction on the surface that the tyre and rim combination move over. By providing a bearing pressure that won't significantly distort the surface, tyres provide a footprint that is designed to balance the weight of the vehicle with the bearing strength of the surface it rolls over. This is achieved by offering a footprint that is created to balance the vehicle's weight against the strength of the surface it rolls over. An elastic cushion is formed when a tyre rolls over uneven ground, absorbing part of the stress that would otherwise be transferred to the passengers (Agwogie, 2012).

Tyres plays an extremely important role in a vehicle since they bear the weight of the vehicle, direct it along paths chosen by the driver, transmit braking and acceleration forces, and absorb bumps and other imperfections in the road surface. As a result of the reasons mentioned above, the combination of the rim and the tyre has been portrayed as one of the fundamental machine elements among the many components that are coupled together to produce an automobile in a number of studies (Adetan, Agwogie, & Oladejo, 2013; Adigio & Nangi, 2014; Pandya & Thakkar, 2015). It is of comparable significance to the vehicle's engine due to the fact that, in the absence of it, the power generated by the engine will not be able to be converted into the movement of the vehicle.

Because of its construction, it is intended to be the sole point of contact between the vehicle and the roadway. The failure of tyres is one of the apparent dangers of traveling by road. A worn-out and air-leaked tyre fitted to a vehicle can lead to failure while the vehicle is in motion, which may cause an accident.

As time passes and tyres are used for their intended purposes, they eventually break down as a result of the wear and tear caused by friction or damage in the form of blowouts. As a result, it is important to replace these tyres. Once the wheel rim and tyre assembly have been removed from the vehicle, tyre technicians can use tyre changer machine or tools to demount and mount tyres on the wheel rim. In Nigeria, the process of removing a tyre from its rim in order to make a repair is traditionally done with the help of a bar by local tyre artisans, who are known as vulcanizers.

Alternatively, the process can be done with the assistance of a support arm in a tyre changer machine that is already in use (Adetan et al., 2013). It is pertinent to point out that the process of changing tyres can be very strenuous, which makes the technician susceptible to injury and the wheel rim susceptible to damage if the appropriate tyre changing tools, machines, or techniques are not utilized during the process of changing tyres. The tyre bead is the diameter of the tyre that is closest to the wheel rim and serves as the point of contact between the two. To stop air from escaping through the gaps between the rim of the wheel and the tyre, the surface of the bead forms a seal there. Bead-breaking is a step that must be completed before changing tyres (Sutar et al., 2017).]

II. LITERATURE REVIEW

1. Conceptual Framework: Tyre, Components, TCM-Design Characteristics and Design Parameters

Tyre

For the reason that it made life simpler, the wheel is widely regarded as one of the most significant achievements in human history. The development of tyres was a response to the growing demand for a more comfortable riding experience that arose as the wheel spread throughout history. Tyres have gone through a number of development phases and stages of improvement since they were first manufactured a century ago. Robert William Thomson invented the first pneumatic tyre in 1845 using his concepts (Sameer, 2018). It was a tube made of canvas that had a rubber coating on it and was covered in leather. During the 19th century, there was a significant need for solid rubber tyres. This particular model of tyre was commonly found on horse-drawn carts and bicycles in the past.

In later years, John Dunlop, a tyre designer, in 1888 developed a tyre that had a tube and rim between the spokes of the wheel. However, in the event of a puncture, the tube had to be removed from the rim, and the outer casing had to be rebuilt.

Charles Welch proposed installing a circle of wire, known as a "bead," on each edge of the tyre as a solution to the problem of the tyre coming loose from the rim. This would prevent the tyre from falling off the rim. A pneumatic tyre is a rubber tyre filled with air under pressure and inserted around the wheel of a vehicle. It widely came into use with the advent of motor vehicles in the 20th century; however, the search for tyres that were more long-lasting, reliable, and safe led to a number of advancements in tyre design, beginning with the single-tube pneumatic tyre and progressing all the way up to the tubeless tyre (Gomesh et. al., 2014). There is a constant requirement to improve the design of tyres in order to boost the reliability of their performance.

A tyre is a torus-shaped rubber covering that surrounds the wheel rim and transfers the weight of a vehicle from the axle to the ground through the wheel rim; it is shown in figure 2.1. A tyre also protects the wheel rim from damage. Due to this, the tyre and rim combination will have better traction on the surface it travels over. Tyres feature a thread that is designed to provide traction, and their bodies are designed to carry a particular quantity of compressed air. As a consequence of this, the great majority of tyres are inflated with air, which creates a resilient cushion that softens the impact of shock caused by the tyre rolling over irregular terrain characteristics. Studies have shown that it is critical to ensure that the correct inflation pressure is maintained in the vehicle's tyres in order to achieve optimal performance in terms of the vehicle's dynamics, braking, and handling (Bo et. al., 2017).

The primary roles of a vehicle's tyres include supporting the vehicle's weight, steering it along paths determined by the driver, transferring braking or acceleration forces, and absorbing road imperfections. For the above reasons, the tyre-rim combination has been defined as one of the most crucial and significant automotive components in several studies.

Components of Tyre

Modern pneumatic tyres are produced from synthetic rubber, carbon black, natural rubber, wire, and fabric, in addition to various chemical components (Ovundah, 2020). Figure 2.2 illustrates the structure as well as the layers that are present in a typical automobile tyre.

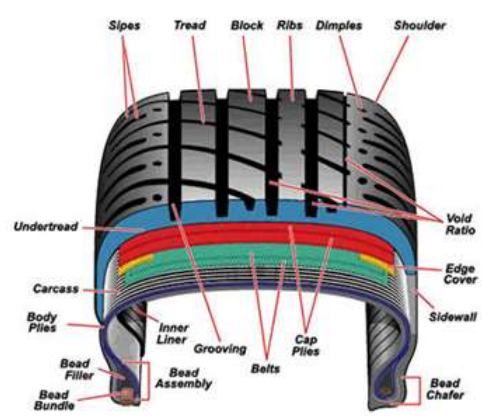

Figure 1: Cross-Section of Tyre Components (Krishna, 2020)

Tyres are one of the most significant safety-related components in vehicles and are found on cars, airplanes, tractors, and a range of other vehicles. The vehicle tyre is a complicated construction made up of numerous, vastly different materials that must function together as a unit. The most common are threads and sidewalls, but underneath are complex webs of materials that make each tyre perform differently. The thread patterns are composed of different rubber blocks, grooves, voids, and sipes that give the tyre its road-gripping power.

A thick pad of rubber into which grooves are moulded generates cleats and ridges that aid in traction while moving or stopping a vehicle, as well as preventing skidding when a vehicle is moving. The tyre features a carcass, steel belts, and plies composed of a fabric that is penetrated with rubber and is often polyester, rayon, or nylon. Varying materials and quantities of belt and ply reinforcing layers make the tyre stronger and capable of carrying different weights. The bead is the portion of the pneumatic tyre that fits and secures the tyre to the wheel rim. They are positioned around the inner border of the tyre and are made up of a coil of high-tensile steel wire that has been treated to have strong adhesion with rubber and is enclosed in a hard rubber hoop (Ovundah, 2020; Adetan et al., 2008). Sidewalls and shoulders provide load flexibility and puncture resistance from road objects.

Tyres fails in static and dynamic situations for a variety of reasons, including manufacturing faults, the complexity of tyre design, a lack of quality control, construction handling; usage conditions, and mounting processes, which often result in a failure that leads to serious accidents. Car’s ride and stop on a few square millimeters of rubber, and because they are a key element of a braking system, a tyre body, inner tube, wheel assembly, and bead assembly must work in harmony. Brakes stop the wheels; tyres stop the vehicle (Adetan et al., 2008). These circumstances impose an extremely high safety factor on tyres, and built-in production flaws may cause tyres to fail dynamically.

The vehicle tyre is a complex construction consisting of flexible materials that can’t be manufactured to close tolerances. About 200 distinct raw ingredients are combined into a one-of-a-kind blend of physics, chemistry, and engineering to provide users with the greatest level of comfort, efficiency, dependability, and performance. The manufacturing process starts with the selection of many varieties of rubber, as well as particular carbon black, oils, pigments, silica, and antioxidants. The diverse raw ingredients for each compound are then combined to make a homogenized batch of a black substance with the consistency of gum (Adetan et al., 2008). The mixing process is computer-controlled to ensure homogeneity. The materials that are compounded are then processed further into treads, tyre sidewalls, and other components.

The inner liner, which is resistant to air and moisture penetration, is the first component to be placed on the tyre manufacturing machine. In the event of tubeless tyres, it serves as the inner tube (Adetan et al., 2008). Then belts and body plies, which are often made from nylon, rayon, and polyester, are added to the machine. Tyres are made stronger and more flexible thanks to the use of plies and belts. Different performance qualities dictate how the belts are shaped and sized; therefore, they are custom-made. All of the tyre's components are represented in Figure 2.2, where they are all integrated and function as one. Due to the fact that the plies run diagonally to each other, we call this kind of tyre "biased-ply." Tyres with radial-direction sidewall cords are known as "radial tyres" (Taheri, 2014). In both cases, the beads and belts are interchangeable.

Two hoops made of steel wire with a bronze coating are implanted into the tyre sidewall to produce the bead. Before pressing all elements into place, the tread and sidewalls have to be aligned and placed on top of each other. A green or uncured tyre is what you get. When the green tyre is inflated in a mould, the tread and tyre-identifying information on the sidewall are formed. This is followed by 12 to 15 minutes of vulcanization, during which they are heated to roughly 2.76

N/mm2 and a temperature of about 148.9 degrees Celsius. Vulcanization is the process in which sulphur is applied to the green tyre. Rubber hardens and loses its stickiness. At the molecular level, rubber goes through chemical changes, and molecules with different parts are physically and chemically connected to make a strong bond (Adetan et al., 2008).

Bead

The bead is produced from high carbon tensile wire and serves primarily to keep the tyre on the wheel rim. Its origins can be traced back to the year 1890, when an engineer named Charles Kingston Welch from Middlesex proposed inserting a circle of wire into each edge of a tyre that fits onto the wheel rim. The wired-on car tyres were set to run at low pressures of 207–24135 kpa (Taheri, 2014). The tyre bead is the connecting link between the road and the vehicle, transferring vehicle load from the tyre to the wheel rim (Adetan et al., 2013).

III. RESEARCH METHODOLOGY

This chapter presents the research methodology that guided the data collection, analysis, and fabrication of the MTCM in this research work. It provides a suitable methodology for achieving the research's aim and objectives.

1. Research Approach

To design, simulate, and fabricate an improved MTCM in Nigeria. The information and data for the design are gotten from primary sources through interviews with the current TCM operators in Rivers State, Bayelsa State, and other parts of Nigeria, as well as from secondary sources through a review of literature Conceptual Design

The concepts for the generation of the tyre-changer machine (TCM) are depicted in this section. They are made up of different components that are assembled together to function as a system. The generated concepts execute the following three functions to carry out tyre repair or replacement:

- Bead breaking
- Tyre extraction
- Tyre insertion onto the wheel rim

Table 1: Decision matrix for evaluating the alternative conceptual design for the MTCM

Criteria	Weighting (100%)	Rating of Suitability of Alternatives		
		Concept Design I	Concept Design II	Concept Design III
Manufacturability R x W	20	10 200	8 160	6 120
Cost (planning, material and fabrication) R x W	20	10 200	10 200	4 80
Feasibility R x W	15	10 150	8 120	8 120
Maintainability R x W	10	10 200	10 200	6 60
Ergonomics R x W	10	10 100	8 80	8 80
Shape and Size R x W	10	8 80	8 80	10 100
Weight R x W	10	10 100	10 100	6 60
Reliability R x W	5	10 50	8 40	8 40
Total Score	100	1080	980	660
Rank		1	2	3
Selected?		Yes	No	No

R rating/score (the maximum score is 10)
W weighting

3. Material Selection

Design in the engineering sector pertains to the design of machines and components created by combining various types of materials. This research utilized mild steel in the form of square tube, circular tube, steel plate, flat and angle bar, as well as the computer-aided design and simulation software required to model and simulate the MTCM machine's operational performance.

4. Design Analysis of the Bead Breaker Part

The bead breaker part of the MTCM has a bead breaker arm that is a circular tube with which a telescoping pry bar can be inserted. As shown in figure 3.15, the pry bar and bead breaker arm assembly will be modelled using second-class lever principle.

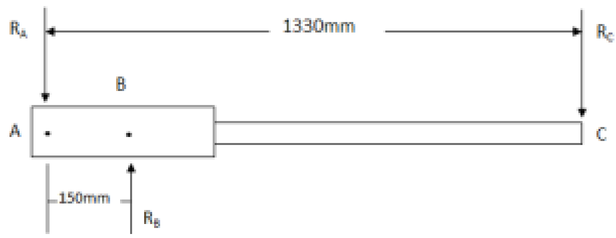

Figure 2: Free body diagram of the pry bar and bead breaker arm assembly of the MTCM.

IV. RESULT & DISCUSSION

1. Results

The analysis of the MTCM design was performed utilizing the design input data, which included the type of material, its mechanical-physical properties, and the geometric data required to create the machine.

Table 2: Machine Design Input Parameters

Input Parameter	Value	Unit
Mass of tyre	150	Kg
Yield strength in tension, Syt	400	N/mm2
Yield strength in shear, Ssy	200	N/mm2
Modulus of Rigidity, G	77×10^9	N/mm2
Length of bead breaker load arm, l1B	150	mm
Length of bead breaker effort arm, l2B	1330	mm
Length of insertion/extraction arm load arm, l1M	250	mm
Length of insertion/extraction arm effort arm, l2M	1430	mm
Length of insertion/extraction arm subjected to torsion, LT	250	mm
Perpendicular distance from the longitudinal axis of the insertion/extraction arm to RL, L	350	mm
Force applied at effort point of insertion/extraction arm and pry bar assembly, RF	733	N
Force applied at effort point of bead breaker arm and pry bar assembly, RC	733	N
Factor of safety, (fs)	5	-

The MTCM's 3-D model was created using the Solid Works 2021 Computer Aided Design (CAD) Tool with data from its design characteristics, and the MTCM's performance was analyzed using Ansys 2021 R2 and Solidworks 2021 workstation.

MTCM Machine Design Input Parameters

Some design inputs were required for computing the design results of the MTCM. These input parameters and their specifications are shown in Table 4.1.

The design equations were applied, and with the required inputs, results were obtained. The design inputs, results and discussions are presented in this section.

V. CONCLUSION

After generating conceptual designs for the manual tyre-changer machine (MTCM), carrying out detailed design of the MTCM, proper material selection, and carried out performance evaluation of the designed MTCM. The following conclusions were drawn from the work:

Decision matrix was utilized for evaluating and selecting the best alternative conceptual MTCM designs. The best conceptual design with a two-bevel gear system and bearing was selected for this work.

Solidworks CAD software was employed to model the improved manual tyre changer machine with respect to the design characteristics.

The analytical values of various machine components were determined from the design analysis carried out on the MTCM.

The 60mm × 60mm × 5mm square pipe was selected for the insertion/extraction arm because it has a lesser angle of twist compared to a 50mm × 50mm × 4mm insertion/extraction arm.

The ANSYS simulation results showed that the maximum value of equivalent stress for the MTCM bevel gear is 4.8699 x 108 Pa. The equivalent stress is larger in the centre and smaller on both sides of the contact surfaces. Likewise, the stress is larger on the junctions of the bottom width angles and pitch angles of the ribbed patterns. The ANSYS simulation results showed that the maximum value of equivalent elastic strain for the MTCM bevel gear is 0.0022615m/m. The equivalent elastic strain is larger in the centre and smaller on both sides of the contact surfaces. Likewise, the elastic strain is larger on the junctions of the bottom width angles and pitch angles of the ribbed patterns. The ANSYS simulation results showed that the maximum value of total deformation for the MTCM bevel gear is 9.654 x 10-5m. The total deformation is smaller in the centre and moderate around its periphery. Likewise, the total deformation is larger on the junctions of the bottom width angles and pitch angles of the gear.

The ANSYS simulation results showed that the maximum value of equivalent stress for the MTCM shaft for pry bar is 34950Pa. The equivalent stress is larger at the joint near the fulcrum represented with a yellow color. The ANSYS simulation results showed that the maximum principal elastic strain for the MTCM shaft is 1.4946 x 10-7 m/m. The equivalent principal elastic strain is larger at the joint near the fulcrum represented with a light green color. The ANSYS simulation results showed that the maximum value of total deformation for the MTCM shaft for pry bar is 5.7215 x 10-8m. The total deformation reduces significantly from the shaft length end section from the right (contact point) to the joint near the fulcrum and then increases slightly from the joint to the fulcrum.

The ANSYS simulation results showed that the maximum value of equivalent stress for the MTCM roller bearing is 3.2406Pa. The equivalent stress is moderate around the larger circumference of the bearing. Likewise, the stress is larger around the smaller circumference of the bearing near the centre. The ANSYS simulation results showed that the maximum value of equivalent elastic strain for the MTCM roller bearing is 7.8388 x 10-10m/m. The ANSYS simulation results showed that the maximum value of total deformation for the MTCM roller bearing is 9.3328 x 10-7m which represents that there is a very little elastic strain and relevant equivalent elastic strain distribution experienced in the roller bearing. These results show that there is fairly good agreement between the analytical results and finite element results.

ANSYS and Solidworks simulation tool applied in this study have shown that it is possible to predict how the machine components will behave in a real case and allows the engineer to see where the stresses, elastic strains, total deformations, and displacements will be the greatest and how the machine will behave with such occurrence. Based on the analysis of the ANSYS and Solidworks simulation results, the stress, strain, displacement, and total deformation concentrates on the machine components will provides a better reference for redesign of the machine.

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